Overcoming the Barriers to Lightweighting by Enabling Low-Cost and High-Performance Structural Automotive Aluminum Castings

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Project ID # mat158

Overview

Timeline

- Start: August 2018
- Finish: Oct. 2020
- % complete (time): ~70%

Budget

- Total project funding
  - DOE: $250K
  - Industrial cost share: $250K
- Future funds anticipated: $0

Technology Gaps/Barriers

- High cost of “primary” aluminum (Al) casting alloys
- Poor mechanical properties of “secondary” Al casting alloys
- Lack of high-strength/high-elongation casting alloys using low-cost casting processes

Partners

- Eck Industries

Relevance/Objective

- Aluminum content in light-duty vehicles
  - Current: 400 lbs. Al/vehicle; ~73% castings
  - Near future: ~500 lbs. Al/vehicle by 2025
- Challenges for greater Al usage
  - Higher cost of “primary” Al casting alloys
  - Poor mechanical properties of “secondary” Al castings
- Project scope
  - Heat-treatment techniques to lower processing cost of castings
  - Molten Al processing technique to enhance mechanical properties of “secondary” Al casting alloys
- LightMAT’s resources (at PNNL)
  - Proprietary heat-treatment techniques
  - Ultrasonic-based molten metal processing

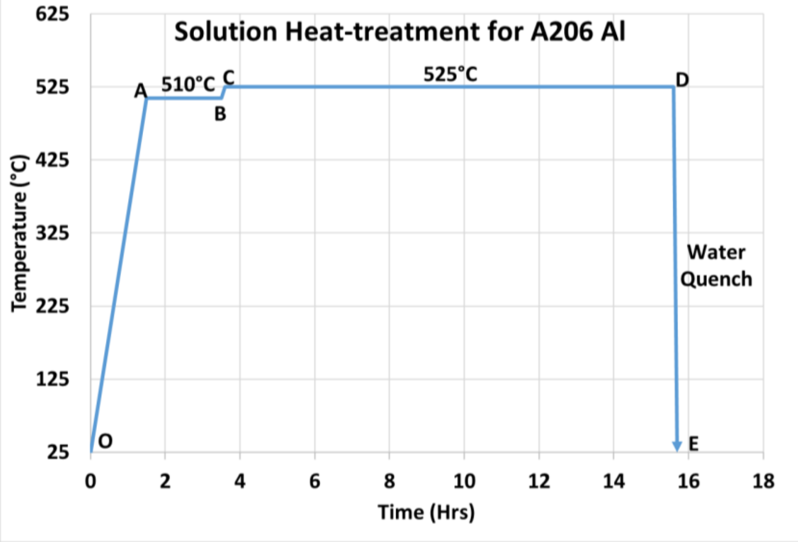
Knuckles

Brake Calipers

Approach

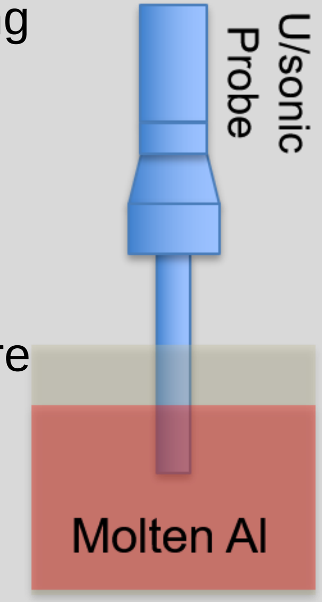
Heat-treatment Development

- A206 Al alloy: 4.6% copper (Cu) – 0.35% manganese (Mn) – 0.25% magnesium (Mg) – 0.22% titanium (Ti)
- PNNL proprietary
- Goal: Shorten solution/aging



Molten Al Process Development

- A356 Al alloy: 6.5–7.5% silicon (Si), 0.25–0.45% Mg, iron (Fe)…
  - 0.2% Fe (“primary alloy”)
  - 0.6% Fe (“secondary alloy”)
- Ultrasonic melt processing
- Goal: Refine the microstructure for finer intermetallics and lower dendrite arm spacing to improve ductility and more uniform properties throughout the casting

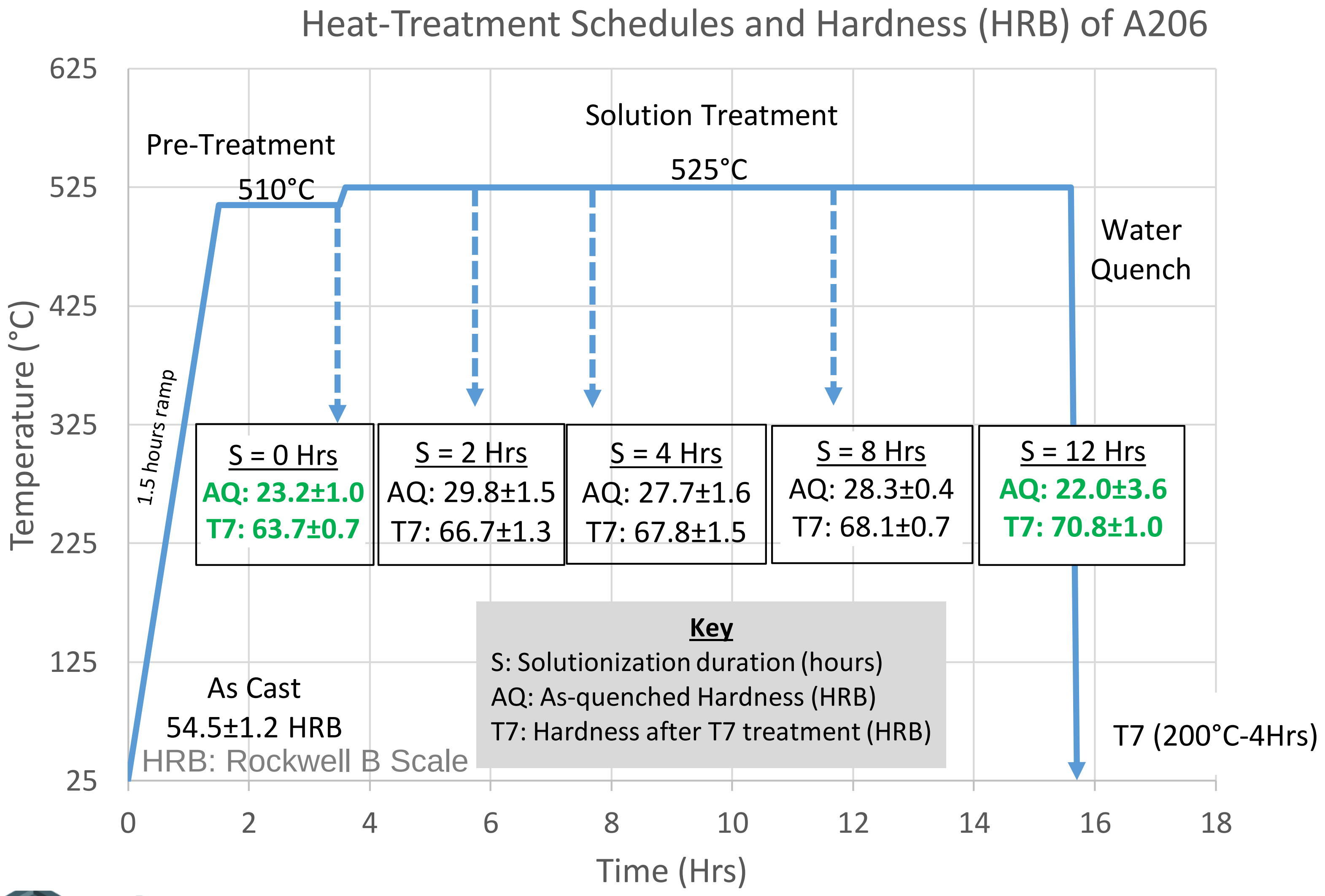


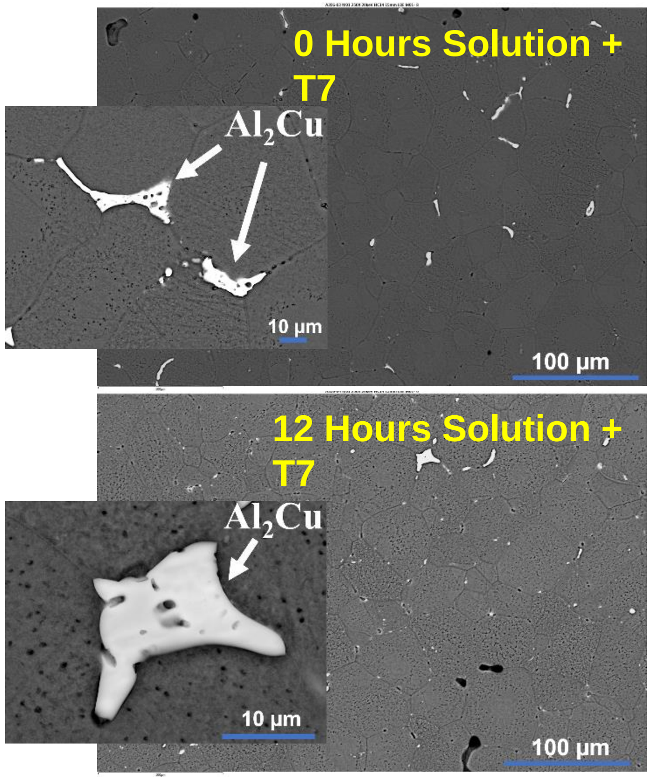
Task/Milestone Summary

Task Name/Duration	'18-Q4	'19-Q1	'19-Q2	'19-Q3	'19-Q4	'20-Q1	'20-Q2	'20-Q3	'20-Q4	'21-Q1
Task 1 Alloy Selection										
Task 2.1 Thermal Analysis of Selected Alloy										
Task 2.2 Design of Ultrasonic Setup			M							
Task 2.3 Solidification Under Ultrasonic Field						M				
Task 3 Heat-treat Process Development					M					
Task 4 Microstructural Characterization										
Task 5 Mechanical Property Characterization										

M1 (03/19): Set up an ultrasonic system for use in conjunction with molten alloys **- Achieved**
M2 (07/19): Compare hardness and microstructure of A206 following the baseline and the alternate heat-treatment performed for the same duration **- Achieved**
M3 (10/19): Compare microstructures of A356 cast with and without ultrasonic processing **- Achieved**

Accomplishments (Heat-treatment)
Baseline Property Measurement (FY2019)



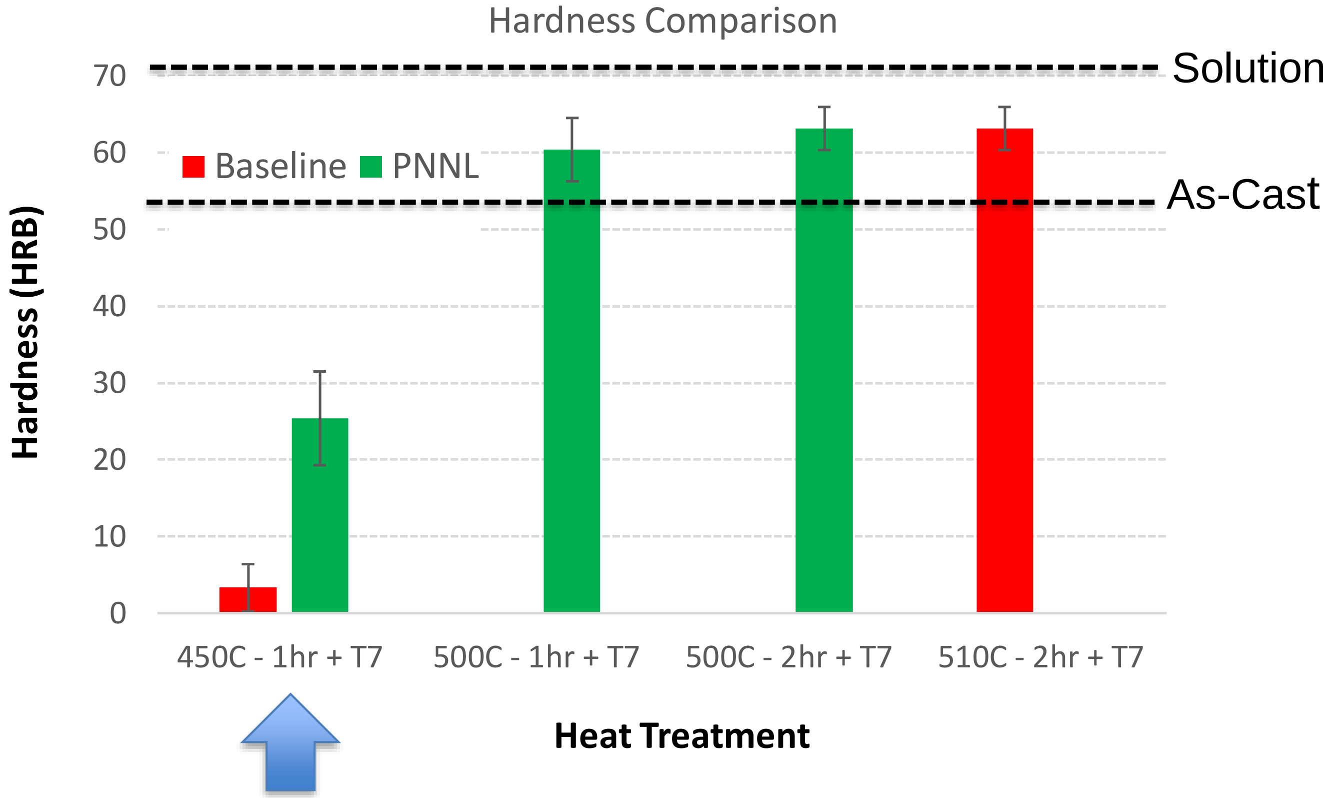


- Maximum age-hardening after 12 hours of solutionizing
- Dissolution of Al_2Cu precipitates during solutionizing

LightMAT

Accomplishments (Heat-treatment)

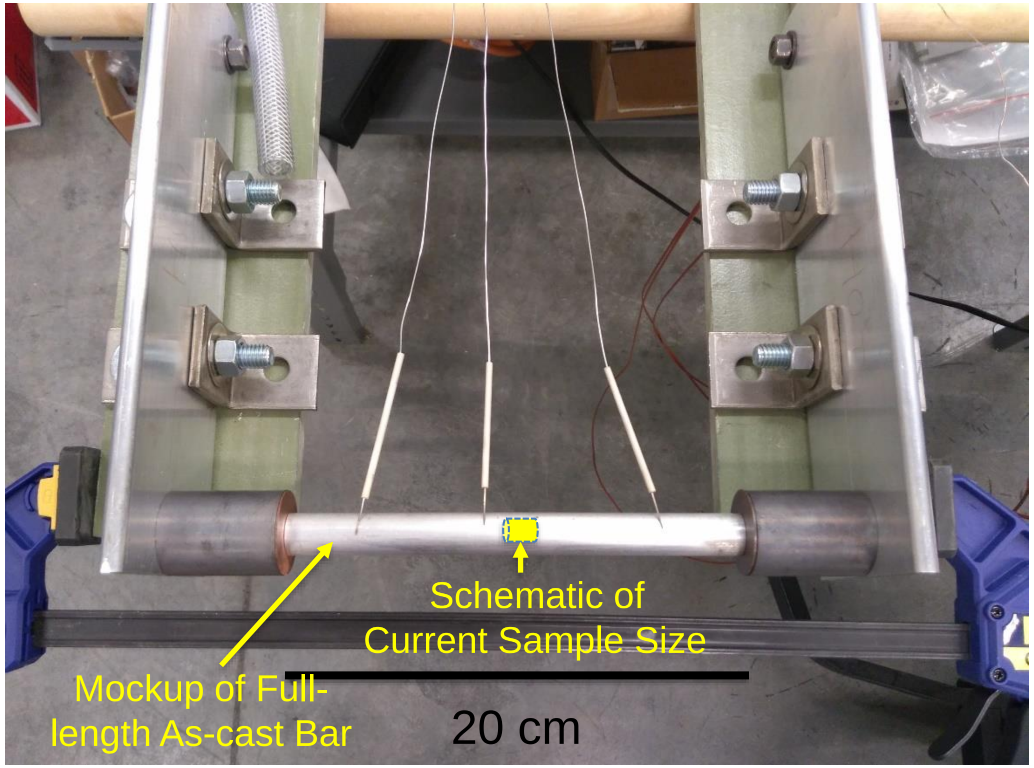
PNNL Heat Treatment vs. Baseline



450°C Baseline as-quenched: 4 HRB
450°C PNNL as-quenched: 11 HRB

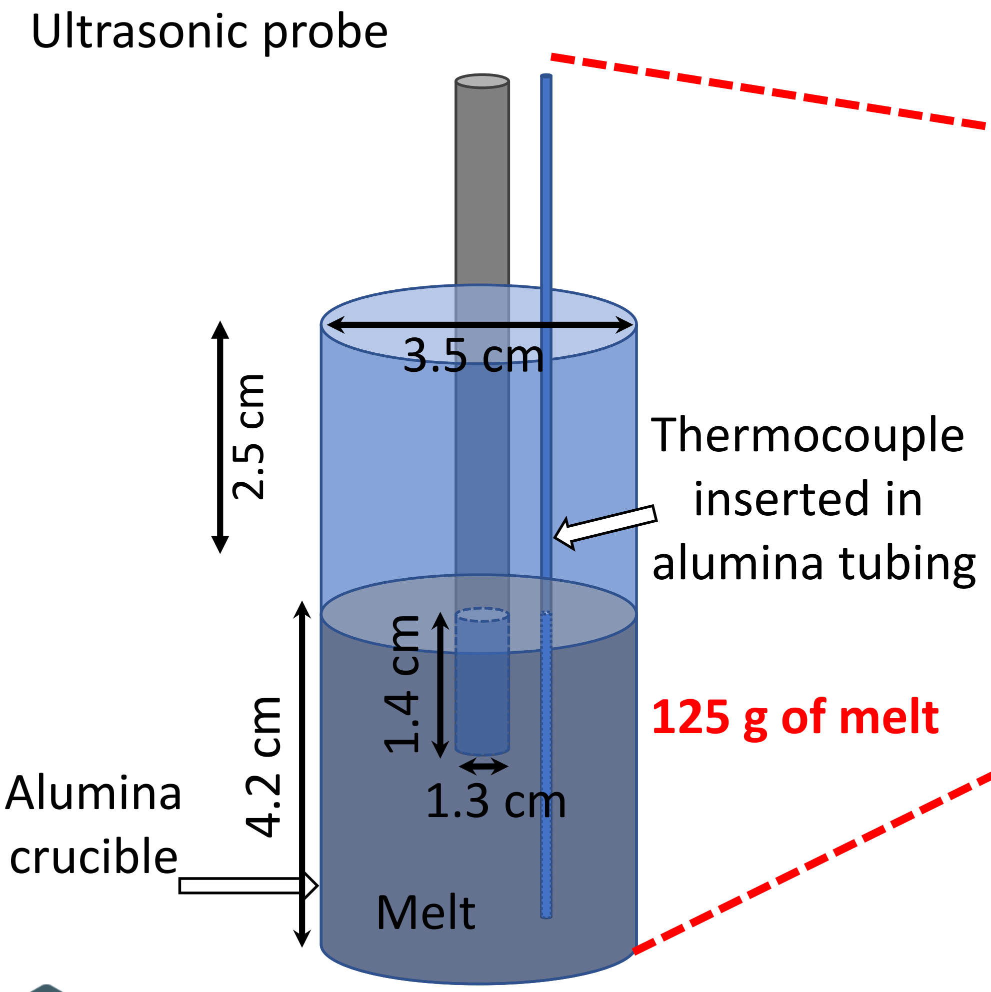
- 450°C-1 Hr. (Baseline/Conventional)
  - No solutionization (very low hardness) → Hardness does not increase after T7 treatment
- 450°C-1 Hr. (PNNL)
  - Some solutionization → Hardness increase from 11 HRB to 25 HRB after T7 treatment
  - Longer solutionization at 450°C by PNNL technique may increase T7 hardness to that achieved by solutionization at T > 500 °C
- 500°C (PNNL) vs. 510°C (Baseline/Conventional)
  - Similar age-hardening efficacy relative to each other, but lower efficacy than the baseline 12 hr. solutionization

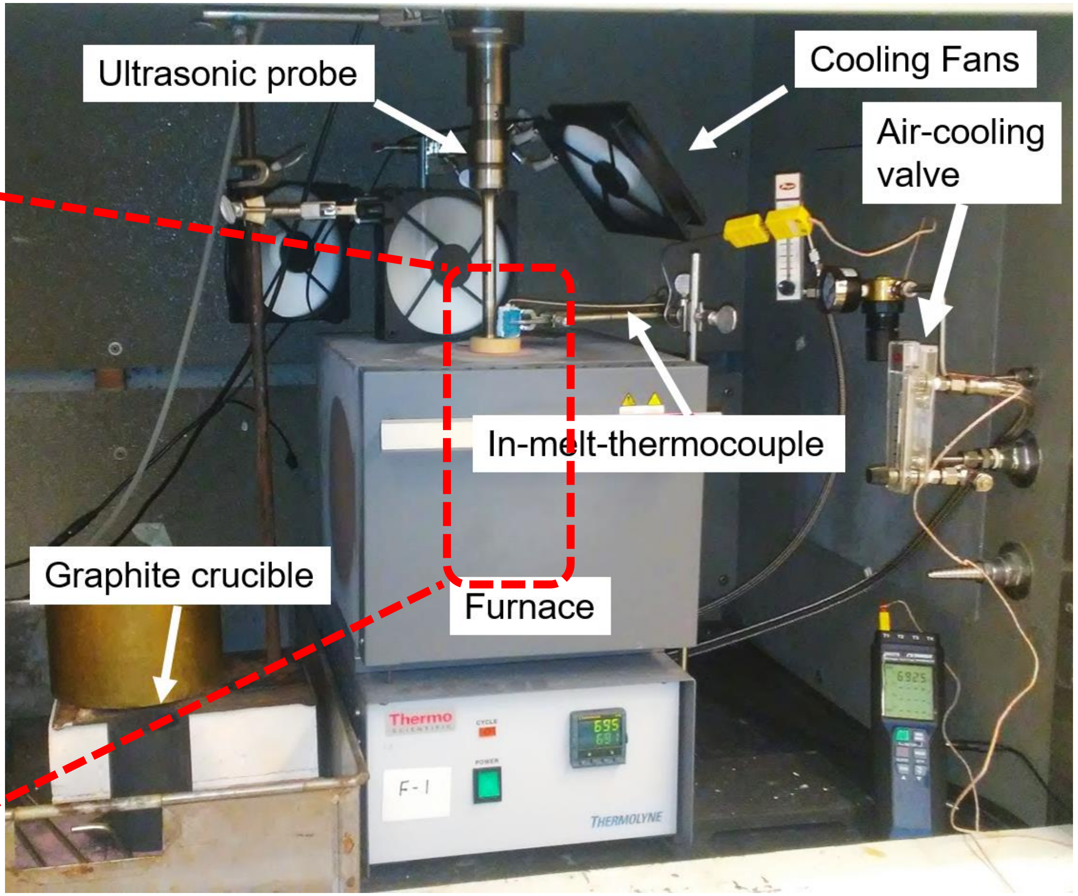
Accomplishments (Heat-treatment)
Scale-up Trials



- Modified setup and conducted mock-up trials to physically accommodate full-length as-cast tension bars
- Performed trial runs to determine heating behavior of long bars vs. currently used small cylindrical samples
- Guidance for implementing the heat-treatment process to the commercial, large-sized castings

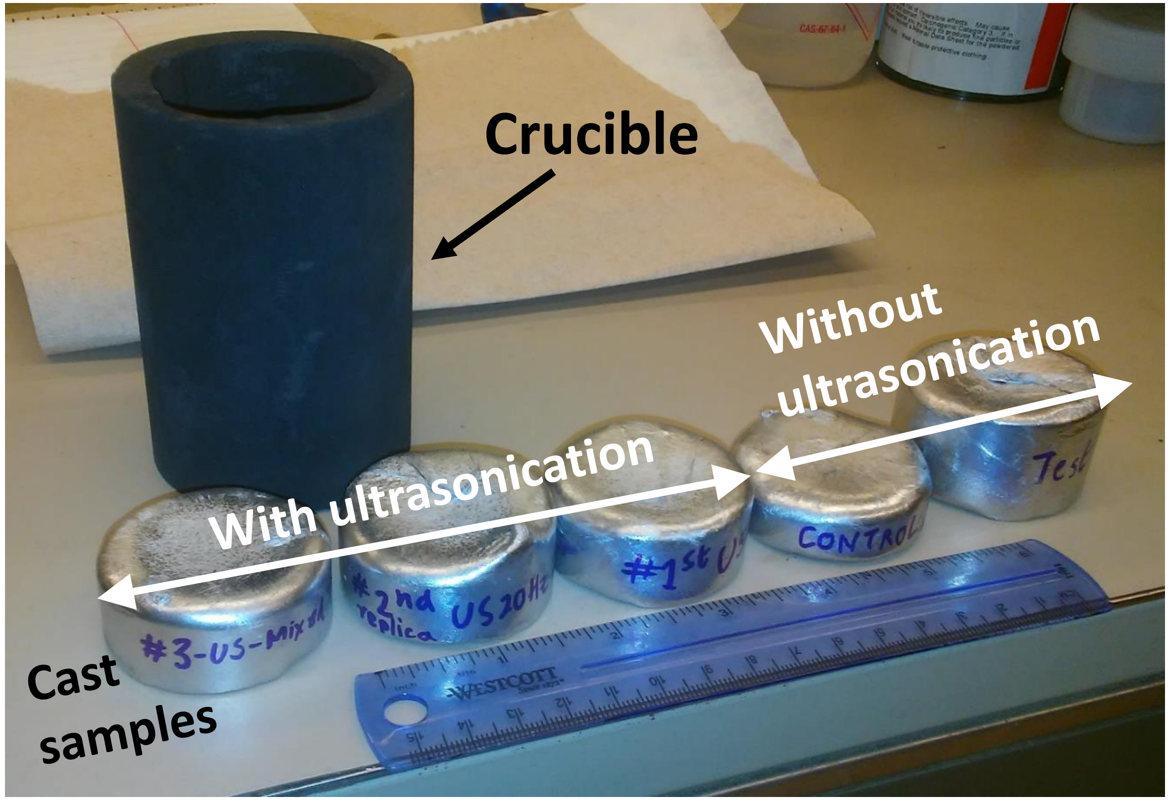
Accomplishments (Melt Processing)
Setup for Ultrasonic Processing (FY2019)





- System is fully functional

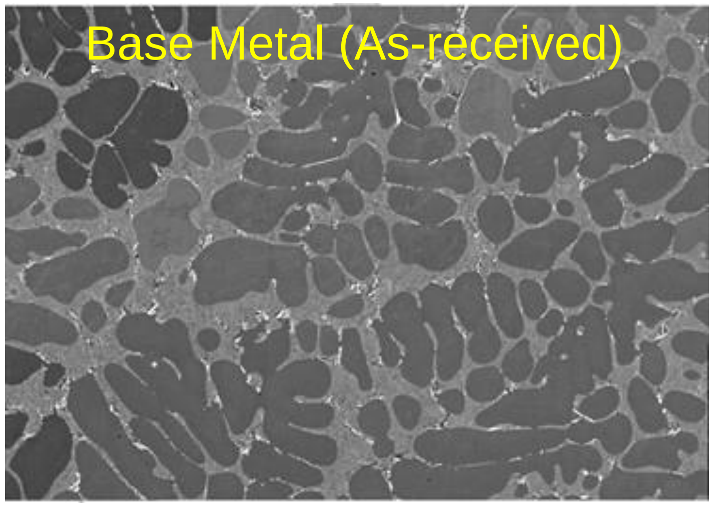
Accomplishments (Melt Processing)
Process Parameters

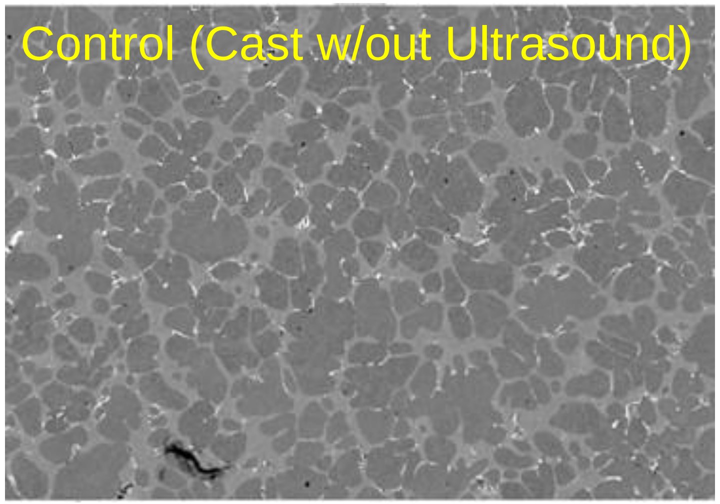


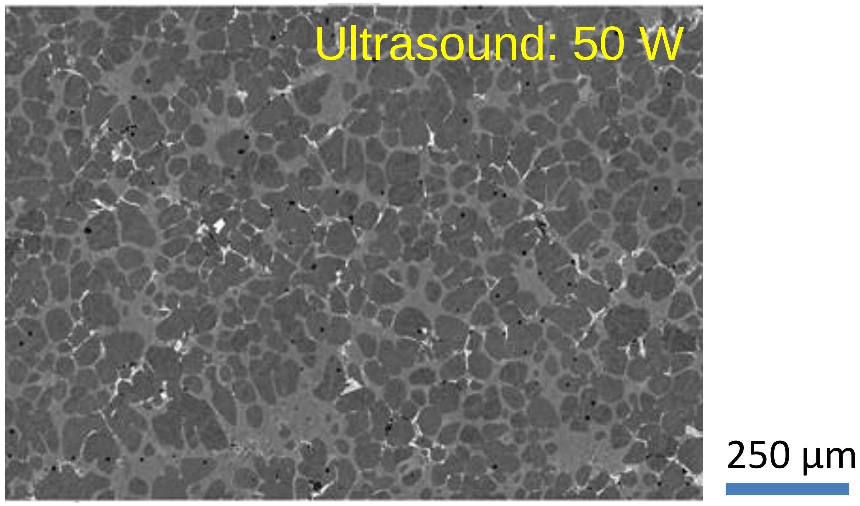
	Ultrasonication	Ultrasonic Intensity (W/cm^2)	Duration of Treatment (s)	Total Energy Input (J)
Low Fe (0.2 wt%)	Control	0	0	0
	25% Amp – 20W	15	120	2400
	40% Amp – 50W	38		6000
High Fe (0.4 wt%)	Control	0	0	0
	25% Amp – 20W	15	120	2400
	40% Amp – 50W	38		6000

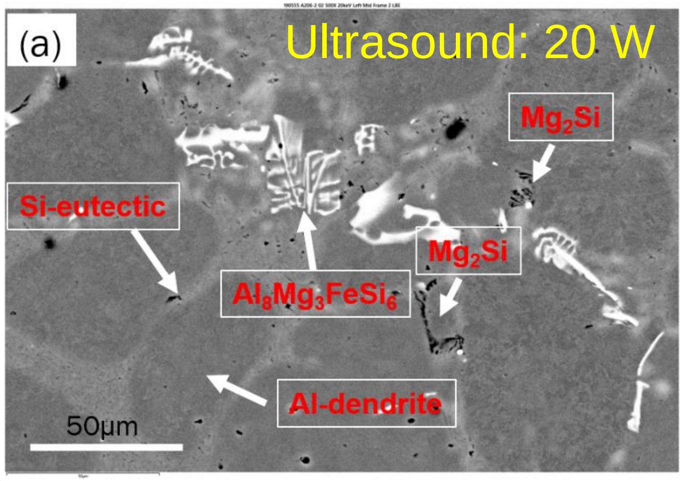
- Samples were processed at two power settings and durations
- Low-Fe: Fabricated samples for microstructural characterizations
- High-Fe: Fabricated samples for microstructural and tensile testing

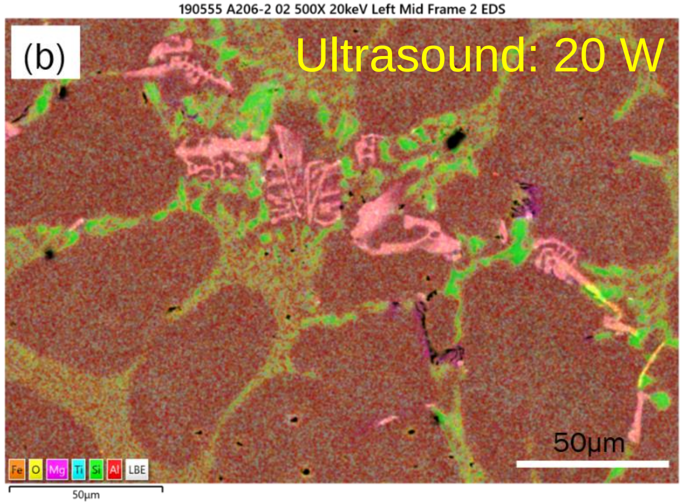
Accomplishments (Melt Processing)
Low-Fe A356 – Microstructures







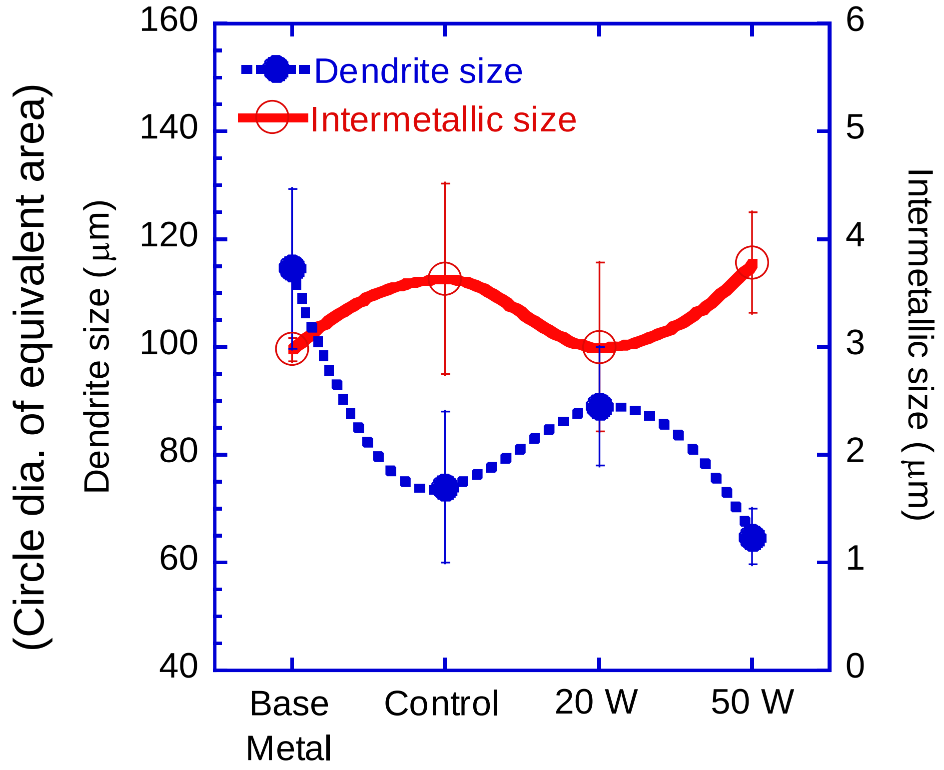


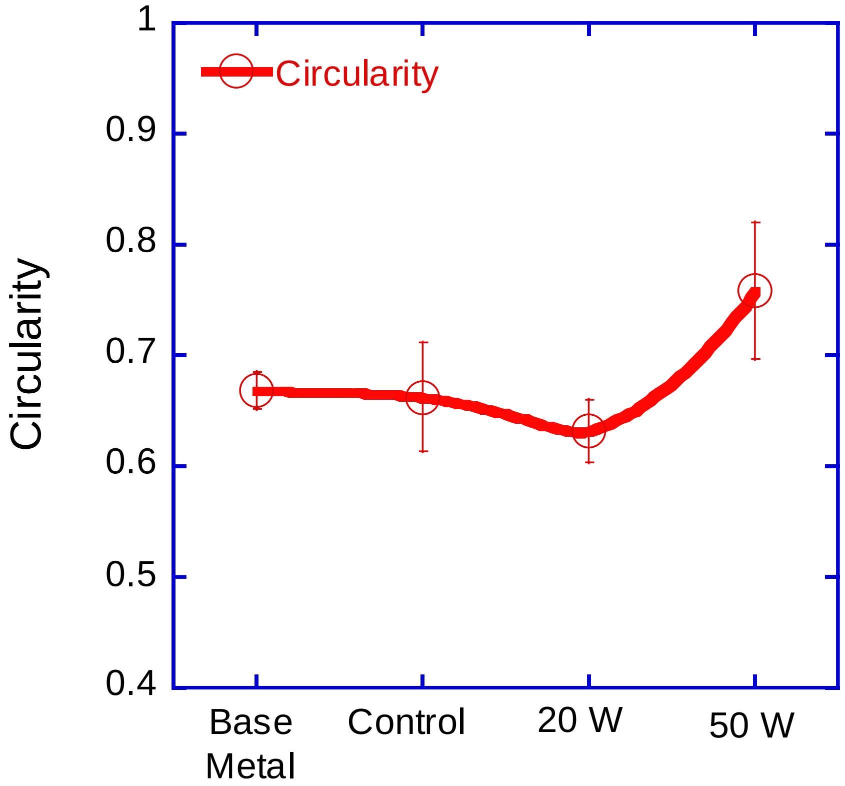


- Performed SEM imaging of low-Fe samples and image analysis to quantify dendrite size and intermetallic circularity
- Suppression of needle-like detrimental β-AlFeSi phase
- Intermetallics with Chinese script morphologies are observed, which are beneficial for ductility [Tash et al., MSEA, 2007]

Accomplishments (Melt Processing)

Low-Fe A356 – Dendrite and Intermetallic Refinement





$$\text{Circularity} = \frac{4\pi\,(area)}{perimeter^2}$$

Circularity = 1 (circle)

Circularity = 0 (perfect oblate)

- Slight refinement of Al dendrites after high-power u/sonication
- Slight coarsening in intermetallic sizes
- Greater uniformity (smaller scatter bar) after high-power u/sonication

- Significantly blunt (i.e., high radius of curvature) intermetallic particles after high-power ultrasonication

Responses to Previous Year's Reviewers' Comments

- No reviewer comments

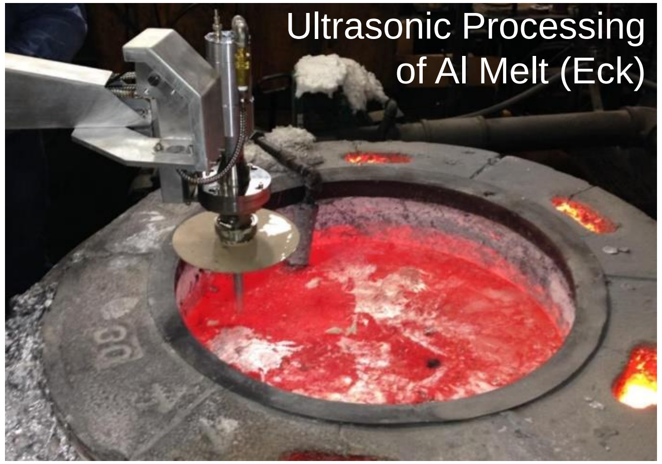
Collaboration and Coordination

Eck Industries

- Supplier to automotive OEMs and Tier-1
- CRADA between PNNL and Eck
- Al alloys supplied by Eck
  - A206 as-cast tensile samples for heat treatment
  - Primary A356 ingot with “low” Fe% and A356 with “high” Fe% to mimic secondary alloy
- Baseline heat treatments
- Tensile testing of ultrasonicated samples and heat-treated bars

Remaining Challenges and Barriers

- Optimize heat-treatment parameters for A206 Al to increase its T7 hardness from current levels
- *Stretch goal: Demonstrate tensile property improvements in heat-treated tensile bars*
  - *Potential equipment limitation for heating long-bar geometry samples*
- Demonstrate intermetallic size refinement and associated improvement in tensile strength and ductility in ultrasonicated high-Fe A356
- Techno-economic feasibility of these techniques, though outside the scope of this work, needs to be addressed, such as:
  - Throughput (e.g., number of parts per run; lbs. molten metal per run)
  - Investment in new equipment vs. existing equipment



Proposed Future Work

- A206: Complete heat-treatment runs with optimized process parameters
  - Measure hardness and tensile stress–strain curve (ductility)
- A356: Complete melt processing of low- and high-Fe samples
  - Measure tensile stress–strain curves (ductility)
  - Ultrasonic processing in semi-solid state and/or at higher ultrasonic power
- Microstructural characterization
  - A206: Dissolution of Cu-containing phases during solutionization
  - A356: Morphology and size/size distribution of Fe-containing brittle intermetallic phases in high-Fe samples

Any proposed future work is subject to change based on funding levels

Summary

- Although opportunities exist to enable greater use of Al castings for automotive lightweighting, greater cost of primary alloy and poor properties of secondary alloys are a hinderance
- PNNL heat-treatment process (for A206 Al) shows the potential of being an energy-efficient alternative to the conventional heat treatment
- Ultrasonic melt-treatment processing of A356 Al shows slight refinement of dendrite size and blunting of intermetallics without any significant size change → Potential to improve ductility of secondary 356 Al